OBSERVATIONS ON THE ANATOMY AND PHYSIOLOGY OF THE CENTRAL NERVOUS SYSTEM.

by

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PREFACE.

During the last few years my attention has been specially directed to the study of the clinical and pathological aspects of Diseases of the Nervous System. After leaving the University of Edinburgh these studies were mainly carried out at the National Hospital for the Paralysed and Epileptic, Queen Square, London. But during the past sixteen months I have had the opportunity of investigating from the experimental side some points in the Physiology of the Central Nervous System, in the Neuro-pathological Laboratory, King's College, where I have had the advantage of working in association with Professor Ferrier. The following Thesis which I have the honour of presenting to the Medical Faculty of the Univ. of Edinburgh for promotion to the degree of M.D. embodies the results of experimental and histological work which has engaged my attention during that time. Chapters I and II deal with an experimental and histological investigation into the paths of the conduction of sensory impressions by the spinal cord and the restitution of function in that structure : while Chap. III is devoted to the clinical and pathological examination of a case of chronic bulbar paralysis and the deductions which have been drawn from it upon the origin of some of the roots of certain of the

C O N T E N T S.

CHAPTER I.

On the Paths of sensation in the Spinal Cord and Medulla Oblongata.

CHAPTER II.

On the restitution of function in the Spinal Cord.

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CHAPTER III.

On the origin of certain cranial nerves.

CHAPTER I.

ON THE PATHS OF SENSATION IN THE SPINAL CORD AND MEDULLA OBLONGATA.

CHAPTER I.

ON THE PATHS OF SENSATION IN THE SPINAL CORD AND MEDULLA OBLONGATA.

I. Brief historical résumé of the views upon sensory conduction in the Spinal Cord.

There is scarcely a subject in the physiology of the Central Nervous System which has given rise to more diversity of opinion, or has offered a greater field for research, than the delimitation of the paths which subserve common sensation. It would not be possible within the limits of this Thesis, to survey the whole of the work already done on this subject. It will be sufficient to state merely the outlines and to refer in greater detail to recent work, more especially in this country, which is tending to cause an alteration in the views of Sensory Conduction.

It may be stated at the outset that the two extremities of the central nervous apparatus, the spinal cord and the cerebral cortex, have been more productive in definite facts than the intermediate portions, the mid and hind brains; and the reason of this is obvious, for while the former may be the seat of extensive disease in Man, or experimental destruction in animals, similar lesions of the latter are incompatible with life. But notwithstanding this, even at the present time there exists much

diversity of opinion both as to the actual paths of sensation in the spinal cord, and the sensory centres in the cerebral cortex.

In 1850 Dr. Brown-Sequard (1) showed, both from the effects of disease in man and from experiments made on guinea-pigs, that all forms of sensation with the exception of the muscular sense, were conveyed up the side of the Spinal Cord opposite to the entrance of the posterior nerve roots; in other words, that the sensory fibres entering the cord by these nerve roots decussated immediately after, or within a short distance of their entrance.

"The spinal cord of a Mammal is laid bare at the level of the two or three last dorsal vertebrae and a lateral half of the organ is divided transversely. It is then ascertained that sensibility seems to be much increased on the posterior limb on the side of the section (hyperaesthesia), while it seems to be lost or extremely diminished in the posterior limb on the opposite side (anaesthesia)".

This observer also noted that if after making a hemisection of one side of the spinal cord, the other half was divided at a higher level, the hind limb on the side opposite the second hemisection lost its sensibility.

If the spinal cord was divided in the lumbar region in the median plane of the body, the result was found to be, retention

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(1) Brown-Sequard. Societe de Biologie - 1850.

of voluntary movements in the posterior limbs, with loss of sensibility in them.

Schiff (1) on the other hand has stated, that although some forms of sensation, notably pain, probably passed by way of the central grey matter, the fibres which subserve tactile sensibility passed up the posterior columns of the cord on the same side. For example, a rabbit one half of whose spinal cord had been severed with the exemption of the posterior column, was awakened from sleep when the hind limb was touched, but exhibited no sign of pain when nerves were pinched, or when needles were passed through the skin.

The experiments of Ludwig and Woroschiloff (2) upon rabbits showed that the paths of the sensory fibres were more limited than this. They pointed out that afferent impressions could be conveyed to upper parts when both the anterior and posterior columns and the central grey matter were divided, when indeed, there only remained the lateral columns. There is reason to believe, from a consideration of their experiments, that many of the conditions which they regarded as indicative of sensation were of a reflex nature, although their experiments probably point to what is the actual path of sensation, viz., the lateral columns. Clinical evidence is distinctly in favour of Brown-Sequard's hypothesis. I have collected fifty-nine cases of the paralysis called by his name (3) and in all sensation

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(1) Schiff. Physiologie. 1859.
(2) Ludwig and Woroschiloff. Der Verlauf der motorischen und sensiblen Bahnen &c. 1874.
(3) Brain. Vol. XIV, p.496.

was abolished or defective on the side opposite the lesion.

Investigators have recently in this country been induced to take up the consideration of this subject again, and at the present time sensory conduction by the spinal cord is the basis of much investigation.

Dr. Ferrier (1) holds strongly to the views of Brown-Séquard, from experiments which he has made upon monkeys. He performed a hemisection of the spinal cord and showed that in the lower limb on the side opposite the lesion anaesthesia to tactile and painful impressions existed, while response to cutaneous stimulation was readily evoked on the paralysed side. In another case section of a portion of the cord, in which the anterior and posterior columns, the grey matter and the lateral limiting layer were not involved produced no anaesthesia; while in a third instance division of the median portions of both posterior columns produced no loss of cutaneous sensibility. These experiments favour the view of Ludwig and Woroschiloff, that the lateral columns of the cord probably convey sensory impressions, and suggest that the fibres lie in close relation to the grey matter.

Dr. F.W.Mott (2) has recently performed a series of experimental hemisections on the spinal cord of monkeys, and has obtained results which tend more to support the views of Schiff than those of Brown-Séquard and Ferrier. His views briefly are, that all seneory impulses do not decussate in the spinal cord;

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(1) Ferrier. Brain. April 1884, and Croonian Lectures, 1890.
(2) F.W.Mott. Phil: Trans: Vol.183, 1892. B. pp.1-60.

that certain sensory impressions, e.g. touch, the muscular sense and "localisation in space" pass up the same side, painful impressions up both sides of the cord. He bases these opinions on the following facts: - Pricking with a needle evokes response on both sides below the hemisection, but more readily on the side opposite the lesion; on dipping the toes into hot water a longer duration of stimulation is necessary on the paralysed side before withdrawal, while the monkey always removes a clip from the non-paralysed leg, but never from the paralysed. This investigator states that the experiments of Homén, Osawa, and Weiss on dogs, are confirmatory of his observations on monkeys.

The observations of Messrs. Gotch and Horsley (1) lead to the same conclusion as those of Dr. Mott. They have found that in cats after hemisection of the spinal cord sensibility is delayed or defective on the paralysed limb; thus in one animal four months after the operation, "on allowing the feet to touch cold water, the hind limb on the side opposite the lesion was smartly drawn up, the other only after considerable delay". And they further state that the application of water and other tests to the skin, indicate that the afferent stimulus was conveyed from both hind legs up the cord, but with much greater certainty, and judging by the quickness of the evoked movements with much greater intensity on the uninjured side than on that corresponding with the lesion. These observations were recorded during the course of an experimental research upon

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(1) Gotch and Horsley. Croonian Lectures - 1891. Phil: Trans: 182. B. pp. 267-526.

afferent conduction by the spinal cord, and the method which they employed was an electric one. Their experiments showed that the electrical change produced by the passage of an impulse is conducted along the structures on the same side of the cord as the nerve which is stimulated. These observers are inclined to the views of Schiff that the main path of afferent conduction is by the posterior columns on the same side of the cord. Where, however, the degenerative and the electro-magnetic methods are considered it is apparent that no distinction can be drawn by their means, between paths which are centripetal and those which subserve sensation, apart from other afferent impressions.

Resembling somewhat in principle the experiments of Ludwig and Woroschiloff are those of Miescher (1), who estimated the effect of stimulation of the sciatic nerve upon the general blood pressure. These observations are therefore open to the same fallacies, when deductions are drawn from them regarding the paths of sensation; firstly, they offer no indication of sensation by the animal; and secondly, they do not distinguish between afferent impressions and those which are essentially sensory.

It is evident then that the difficulties in the way of defining the course of the sensory tracts are not readily overcome and they are mainly of two kinds. Firstly, the difficulty of testing sensation in the lower animals, and the fallacies which

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(1) Miescher. Referred to by Dr. Mott (op. cit.) Ludwig's "Arbeiten" 1870 p.172.

beset such investigations; and secondly, the peculiar anatomical arrangements of these fibres, whereby they differ from the motor or other centripetal tracts. The latter are long, unbroken strands of fibres, having at one end a trophic centre regulating their nutrition, and therefore readily detected by the degenerative method; the former are, in all probability, short, repeatedly interrupted fibre-tracts, which are not prone to degeneration.

II. Object and nature of the research.

My intention in the succeeding pages is -

1. To record the results of a series of experiments upon monkeys, undertaken with the object of explaining, if possible, the discrepancies which exist between the results of earlier and later observers; and,

2. To endeavour to eliminate by a careful anatomical and physiological study of the structure of the Spinal Cord and Medulla Oblongata, the paths by which sensory impressions are conducted from lower to higher parts of the central nervous apparatus.

The experiments were performed, and the observations made in the Neuro-Pathological Laboratory of King's College, London, under the superintendence of Professor Ferrier. The anatomical investigations were also carried out in the same laboratory, and my thanks are due to him for placing at my disposal the material and necessary apparatus. Monkeys were exclusively used in the experiments, being easily handled, and admitting of conclusions

which may be readily applied to Man. Dogs and cats have been extensively used by other investigators, especially by Gotch and Horsley, Schiff, Brown-Séquard, Weiss and others.

III. Methods of operation and observation.

The method of operation was similar in each experiment. The monkey having been anaesthetised with chloroform, the skin was rendered aseptic by thorough cleansing with a solution of Perchloride of Mercury (1 in 1000). A mesial incision was then made over that portion of the spinal column where the hemisection of the cord was to be performed. The muscles were cleared from the spines and laminae, and the vertebral canal was opened by the removal with the bone forceps of the posterior arches of two or three vertebrae. The dura mater was incised mesially, and at either end of the incision two oblique cuts were made outwards, so as to reflect the theca and expose the entrance of the posterior nerve roots. The posterior median fissure, which is usually obscured by a blood-vessel, was defined, and a grooved transfixion knife passed through the cord in the middle plane of the body. A sharp cutting knife was then passed along the groove and one half of the cord severed. The wound was thereafter closed. Strict antiseptic precautions were taken, and the wounds healed by the first intention.

The method of observation was as follows: - The monkeys were tested as much as possible under normal conditions; they were never used for experimentation until they had become accustomed to the laboratory. When investigating the condition

of sensation they were allowed to lie quietly before the fire and associate with other monkeys. (A very convenient way to test a monkey is to place it in a small cage by itself, so that it can be approached from either side without its attention being attracted.) I have found that placing the animal upon the knees of an assistant is not so satisfactory as the above method unless the animal is perfectly tame and docile. All possibility of the use of the special senses was rigidly excluded. The investigation of conditions of sensation in animals is fraught with difficulty and perhaps fallacy, as the results obtained may be differently interpreted. But the two chief difficulties are: -

1. Complications arising from reflex action; these have been as far as possible, rigidly excluded. 2. The presence of sensation can only be inferred by movements, but it is perhaps possible that sensation may occur not evidenced by movements.

1. Reflex action. It was constantly observed that on the side of the operation, the reflexes both superficial and deep were much diminished or altogether absent; while on the opposite side they were increased, especially those of the skin of the foot of the opposite lower extremity. For example, when the sole of the foot on the non-paralysed side was touched with a hot wire, pinched, or dipped into hot water, a sudden reflex withdrawal of the limb occurred. This might be readily mistaken as evidence of sensation on the side opposite the lesion, but it was observed, that until restitution of sensation occurred,

no signs of annoyance or discomfort were noted; on the other hand, on the side of the lesion, no such withdrawal took place, by reason of the paralysed state of the limbs and the diminution of the reflex excitability, when the limb was similarly irritated; but evidence of the perception of sensation was invariably obtained, by struggling, or attempting to bite, or to move away from the source of annoyance.

2. The evidence of the perception of sensation in the animals, on which the experiments have been made, was inferred entirely from the movements which resulted from the application of a stimulus. That this is open to fallacy no one doubts, for although the movements which result are indicative of the perception of sensation, either tactile or painful, it is possible that sensation may occur not evidenced by movement.

IV. Record of the Experiments.

Experiment 1. Macacus Rhoesus. Male. A section of the right side of the spinal cord at the level of the ninth dorsal nerve root was made on April 11th 1891. On the day following the operation, which is regarded as the first day of observation and when all appearance of shock had passed off, the following condition was noted: There was complete paralysis of the right lower limb, while the left, although it was freely moved when the animal lay upon its back and tried to escape, was not used for prehension when climbing the lattice-work of the cage. Its attention was at once arrested by ruffling the hair, pricking, pinching, and the application of a dull hot wire to the skin of

the right lower limb, while it paid absolutely no heed to any of these forms of stimulation on the left. There was no reason to suppose from the manner in which it responded to the various forms of irritation that they were felt more keenly than normal. The superficial reflexes, especially the plantar, were much more active on the left side than on the right or paralysed limb. This condition remained until the third day, when, on touching the region of the left knee with the hot wire, the monkey would bring down its hand and scratch, but never struggle or show signs of discomfort. On the fifth day when pricked with a pin about the left knee, but much more evidently when the hot wire was applied to the limb generally, it brought its hand down to the place touched and localised it. It took no notice of ruffling the hair on this side. The reaction to cutaneous irritation of the right side remained as before. On the tenth day the physical signs corresponded to those in the last note; it was evident that painful impressions were perceived, but much less readily than on the right limb. On the twenty-fourth day for the first time, the "clamp test"(Schiff) was introduced into the routine of testing, and this revealed interesting facts not altogether easy of interpretation. It was noted that when the clamp was applied to the right leg, struggling and other signs of discomfort immediately ensued, but there was no attempt to remove it, while if it was applied to the left leg, there was no sign of discomfort, but the leg was at once drawn up and the clamp was pulled off. It seemed as if the cause of

this was the excessive reflex action of the non-paralysed side; to overcome this the legs were held and the clamp again applied to the right leg; at once the struggling commenced and continued until the clamp was withdrawn, while the monkey took absolutely no notice as long as the clamp was attached to the left side: on freeing the legs, however, the left was drawn up and the clamp pulled off. This doubtful condition remained for some days, but on the thirty-eighth day the following state was noted The animal took no notice of the pinching with forceps on the left side, but brought its hand down in an indefinite way, when pricked gently at the root of the tail and the lower part of the back, and an equal degree of pricking caused more discomfort on the right than on the left side. When the animal's attention was diverted, ruffling the hair by blowing through a long glass tube invariably caused it to scratch. It did not take so much notice of the dull hot wire on the left as on the right side. The reactions to the clamp remained the same. On the fifty-third day it took notice of pricking and pinching and ruffling the hair on the left leg as it did on the right. From this date onwards it was impossible to say which had been the anaesthetic limb; it responded as readily to all forms of stimulation on the one side as on the other.

Pathological examination. At the seat of the incision the dura mater was adherent to the surrounding bone, the membrane itself being slightly thickened. The spinal cord was removed and hardened in Müller's fluid. After some weeks, sections were

made at the seat of both lesions, and double-stained with the Weigert-Pal and Carmine (Upson's) methods: In the first lesion, at the level of the ninth dorsal nerve, the following features were observed: The incision was filled in by a layer of white fibrous tissue, which extended from the periphery to the line of the central canal. The whole of the right side of the cord had been destroyed, but in addition the left postero-median column. The central grey matter on the left side maintained its normal shape, but its structure appeared slightly altered owing probably to a certain amount of "traumatic degeneration", which had also increased the neuroglia of the white matter lying in close relation to it. (Plate I. fig 1)

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Experiment 2. Macacus Rhoesus: female. Section of the spinal cord on the left side at the level of the seventh dorsal nerve root was made on June 10th 1891. The animal recovered very rapidly from the operation and presented the following features: Complete paralysis and flaccidity of the left lower extremity, while the right was moved well in all directions; although, as occurred in the first experiment, the non-paralysed leg was not used for any useful purpose, as for instance, when it was climbing the lattice work of the cage. This was no doubt due to the fact that owing to the cutaneous anaesthesia, the sense of the position of the limb was lost, and, without the aid of vision it did not know where its right leg was. When the skin of the left leg was tickled, scraped with a blunt instrument, or gently pricked and pinched, its hand was at once brought down accurately to the place which was irritated. Absolutely no notice was taken of any of those forms of irritation when applied to the right lower limb. The superficial reflexes on the right side were markedly exaggerated. By the sixth day the monkey localised correctly the places on the right leg where it was pricked or when the skin was tickled by blowing upon it, but it never struggled or showed signs of discomfort. Similar reactions to the clamp test ensued in this case to those observed in the first experiment. When the clamp was applied to the left side, the animal invariably struggled and appeared annoyed by the presence of the clamp, but never tried to remove it. On the right leg however, it never showed the slightest

sign of any discomfort, even when the clamp was kept applied for several minutes; it was only necessary to free the limb which was being held, when the leg was drawn up and the clamp removed.

During the succeeding weeks when the animal was under observation, the responses to the tests showed little or no variation from what is stated above. All forms of irritation, including the clamp test, arrested its attention when applied to the left leg; on the right leg, however, although pricking, pinching and the hot wire usually attracted notice, the response was obtuse, and a greater severity of stimulation was required. The monkey was killed on the one hundred and twenty-seventh day after the operation.

At the autopsy, the hemisection was found to be at the level of the seventh dorsal nerve root. After hardening the cord for some weeks in Müller's fluid, sections were cut and stained by the Weigert-Pal method. Sections made at the level of the lesion showed that the whole of the left half of the cord had been destroyed, and to some extent also the anterior and posterior median columns on the right side. The space intervening between the cut ends of the left side of the cord was filled with white fibrous tissue, in which there was no evidence of regenerating nerve fibres.

(Plate I. fig. 2.)

Experiment 3. Macacus Sinicus: male. A section of the left side of the spinal cord was made between the third and fourth cervical nerves on May 26th 1891. On the day following the operation, one observed that there was complete paralysis of the left arm and leg. As regards the sensation: - 1. On the lower limbs; the animal paid no attention when it was touched on either leg, but it was dull and apathetic, it however, readily responded by bringing its hand down to the place when it was pricked, pinched, or touched with a dull hot wire on the left leg. No such response was evoked when the right lower limb was similarly irritated. 2. On the arms; all forms of irritation except ruffling the hair at once arrested its attention when applied to the right upper limb, but there was considerable difficulty in determining the exact condition of the left. It took no notice of ruffling the hair by blowing through a glass tube or of gently scraping the surface of the skin with a blunt instrument, while it would struggle slightly or open its eyes when this limb was pinched, pricked, or touched with a hot wire. Owing to its apathetic state it was difficult to estimate the sensibility to touch on the extremities; the sensibility to pain and heat resolved itself as follows: analgesia of the non-paralysed leg, obtuseness of sensibility on the paralysed arm, while the paralysed leg and the non-paralysed arm presented normal reactions; there was no reason to suspect that there was any hyperaesthesia on these limbs. Tickling the sole of the right foot occasioned a lively reflex drawing up of the leg;

the right arm and leg were freely moved.(+)

On the seventh day there was no sign of any return of movement in either limb on the left side, but when the hair on the right buttock and thigh was gently pulled, or the skin lightly scraped or pricked, the animal at once brought down its right hand and scratched the place which was irritated. It was several times seen to spontaneously scratch the right thigh. And further, pricking the right foot and leg caused it to move away or, if held, to struggle. The same notice was taken when the left arm was pricked, but to a much less extent and the prick required to be more forcible. It was able to climb the lattice work entirely by means of its right arm and leg. On the thirteenth day it responded to all forms of irritation (touch,pain, heat) on the left leg, the right arm and the right leg; much difficulty was experienced in ascertaining the sensibility of the left arm; the monkey was never aroused from its occupation when the arm was touched, but when pricked or when the hair was pulled it looked up, but did not show signs of discomfort. On the twenty-ninth day the monkey readily took notice of all forms of stimulation on the legs. As in the first experiment, the clamp was removed from the right leg, but never from the left.

(+) The monkeys illustrating experiments 2 and 3 were exhibited at a meeting of the Neurological Society of London. Prof: Schäfer and Dr. Mott having tested the animals denied the existence of anaesthesia on the side opposite the lesion.

It was still dificult to determine the tactile sensibility of the left arm. It responded to painful impressions, but less readily than on the right side. By the fifty-fifth day there seemed to be no doubt that touching the left arm and hand, or very gently pulling the hairs were felt, because the animal invariably looked round and moved away, when this was done. Its perception of tactile impressions on this limb was distinctly blunted, as also was its perception of painful impressions. On the one hundred and sixth day the sensibility remained the same as at the last note. The monkey died on the one hundred and twenty-sixth day after operation.

Pathological Examination. Owing to a considerable amount of adhesion between the spinal cord, dura mater and vertebral column in the upper cervical region, some difficulty was experienced in removing the cord, with the result that the latter was torn at the seat of the lesion, so that I cannot figure the exact amount of destruction of the cord. Careful examination has been made of the ascending and descending degenerations. The tracts which degenerate upwards are, on the left side, the whole of Goll's column, the direct cerebellar tract, and the ascending antero-lateral tract of Gowers. On the right side of the posterior median fissure there is a small linear area of degeneration in the postero-median column. The descending degenerations are the crossed and direct pyramidal tracts on the left side, and a small portion of the direct pyramidal tract on right side. The lesion itself was situated between the third

and fourth cervical nerves on the left side.

(Plate II: figs 1+2.)

Experiment 4. Macacus Rhoesus: male. A section of the left side of the spinal cord at the level of the third cervical nerve was made on Nov. 3rd 1891. On the day after the operation the state of motion and sensation was as follows: the left arm and leg were completely paralysed, while the right were freely moved at all the joints. All forms of cutaneous irritation applied to the left leg, buttock and flank (gently ruffling the hair, scraping the surface of the skin, pulling the hair, pricking, pinching, and the dull hot wire) at once arrested the animal's attention. When the clamp was applied to the sole of the left foot or to the skin of the leg, struggling at once ensued, but there was never any attempt to remove it, and this continued as long as the clamp remained attached. Absolutely no

notice was taken of any of these forms of irritation on the right leg, buttock or flank, but when the clamp was attached to the right sole the leg unless held, was speedily drawn up and the clamp pulled off. Pricking, pinching, and the clamp forceps gave rise only to slight signs of discomfort when applied to the right upperlimb, while the monkey struggled considerably when the left arm was pricked or pinched, or touched with the hot wire. It paid no heed to gently scraping the skin or ruffling the hair of this limb, although its attention was at once arrested when a drop of water was allowed to fall upon either hand It struggled when the clamp was applied to both hands, but less on the right than on the left side. It never tried to remove the forceps from the left hand.

On the second day the monkey again removed the clamp from the right sole, but there was no evidence of any discomfort when it was applied. It never attempted to remove the clamp from the left sole, although it struggled as long as the pressure of the clamp was kept up. In all other respects, it remained as on the previous day.

On the fourth day the reactions were as at the previous observations, but with this addition, that pricking the right leg or right root of the tail would occasion a slight amount of struggling; as if there were some, but defective, perception of painful impression. On the fifth day the monkey died.

The autopsy revealed a hemisection of the spinal cord at the third cervical nerve; the ends of the divided half of the

cord remained apart. There was no filling in with fibrous tissue.

Experiment 5. Macacus Cynomolgus: male. Section of the left side of the spinal cord between the fourth and fifth cervical nerves. The section was made on Nov. 17th 1891.

On the following day there was paralysis of the left leg, and almost complete paralysis of the left arm, a slight movement at the shoulder joint being occasionally observed. Absolutely no notice was taken of any form of irritation applied to the right lower limb; when the clamp forceps was applied to the sole of the foot or elsewhere on the leg, a sudden spasmodic movement ensued of probably reflex nature but the clamp was never removed, nor was there any attempt at removal. Similar forms of irritation on the left lower limb caused struggling, and attempts to move away; and on the application of the forceps evident signs of discomfort, but no endeavour to remove it. The monkey bore, with only a small amount of struggling, pricking and pinching the right upper limb, but at once responded to a touch either of a blunt instrument or of a drop of water let fall upon its hand. It at once took notice of pricking and pinching the left upper limb, and also when the clamp was applied but one was unable to detect at first any evidence of a sense of contact on this limb, as the monkey paid no attention to ruffling the hair or dropping water on its left hand. On the second day similar tests were employed, but no alteration was noted in the condition of sensation; special attention was

devoted to the tactile sensibility of the left hand, but no evidence of any recognition of tactile impression was obtained. On the third day, however, when the monkey was lying quietly before the fire, a drop of water let fall upon its left hand at once arrested its attention. The right leg remained completely anaesthetic to all forms of irritation. There was no sign of discomfort when the clamp was applied to the limb, nor was there any attempt to remove it. The right arm and left leg remained as before. This condition was confirmed daily until the eighth day, when on applying the forceps to the left arm, the monkey brought round its right hand and tried to remove them, and, further, when water was dropped upon the left hand or when the arm was gently scraped, it looked round towards its hand and attempted to move away from the irritation. This was the first indication of something more than a mere feeling of contact on the paralysed arm. The right leg remained completely anaesthetic to all forms of irritation. There was some increase in the amount of movement noted on the first day, but the animal was yet unable to stand or sit up. On the sixteenth day the right leg remained completely anaesthetic to all stimulation, excepting that when pricked at the root of the tail on the right side, the monkey brought its hand round to the place and scratched it. There was no attempt to remove the forceps from the right foot; although it could sit up, it was unable to progress. It at once responded when touched on the arms and the left leg: pricking the right arm causes less evidence of discomfort than when

the left arm and leg are similarly irritated.

On the twentieth day the monkey correctly localised the place where pricked and touched in the region of the right buttock and perineum. When the clamp was applied there was no sign of discomfort, although the instrument was at once removed. The parts below the knee remained perfectly anaesthetic. The anaesthetic state of the right lower limb received confirmation by the fact that two sores developed as a result of the retention of extraneous matter, of the presence of which the animal was quite unaware. The above condition remained until the fortieth day after the operation when the animal died.

Autopsy. The lesion was found to be between the fourth and fifth cervical nerves on the left side. It was considerably nearer the entrance of the fourth nerve than the fifth. Sections of the cord at the level of the hemisection showed that the whole of the right grey crescent and the white matter on the right side was intact, with the exception of the postero-median column. The anterior median fissure and the central canal were intact and there was a small island of white matter considerably degenerated occupying the region of the left anterior column The left grey crescent, and the remainder of the white matter appeared destroyed; a few islands of broken-down medullated fibres however were present in the cicatrix on the left side. Ascending degeneration was observed in both columns of Goll and the left direct cerebellar and antero-lateral ascending tracts.
[Plate III]

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V. Analysis of the sensory disturbances following hemisection of the spinal cord in monkeys.

These experiments confirm for the most part, the theory originally advanced by Brown-Sequard, that the sensory fibres for the lower limbs, decussate immediately after, or within a short distance of, their entrance into the spinal cord. This does not, however, hold true for the sensory fibres of the upper extremities in the monkey. The facts of the experiments in the upper cervical region show that on the arm opposite the lesion, the sensibility to painful impressions was absent or defective, while the sense of Contact was retained and after some time localised.

On the paralysed arm, with retention of the sense of pain evidence of tactile sensibility was obtained within a short

period of the operation. This would appear to indicate that the fibres subserving tactile sensibility for the arms pass up both sides of the cervical portion of the spinal cord, while those subserving painful sensibility mainly pass up the opposite side. In the case of the lower limbs, the experiments show that the sensory fibres pass up the opposite side of the cord. But it was noted in one or two instances, that although anaesthetic to all other tests, the monkey would occasionally remove the clamp forceps from the lower limb on the side opposite the lesion, and in Experiment 4, this was observed immediately after the operation. This seems to indicate the preservation in some monkeys of a sense, probably a sense of pressure. The removal of the clamp forceps from the otherwise anaesthetic limb has been noted by Dr. Mott (loc: cit:) and has been explained by him as due to a retention of the muscular sense. That animals vary, both in the amount of sensory disturbance which follows hemisection, and in the duration of the symptoms, is evident from the experiments which have just been recorded. In a similar way the recorded cases in Man of lesion in the upper cervical region show some irregularity in the distribution of the sensory defects. In Experiment 5, the intensity and duration of the anaesthesia of the non-paralysed leg was of a very striking nature. That the anaesthesia was complete was further shown by the development of sores at the root of the tail and on the thigh, from the retention of foecal and other extraneous matter, of the presence of which the animal was unaware.

The sensory disturbancesmay be briefly tabulated as follows: -

	Side of lesion.	Side opposite lesion.
Exp. 1. (Lower extremity)	Retention of sensibility to touch and pain.	Anaesthesia. Analgesia.
Exp. 2. " "	Retention of sensibility to touch and pain.	Anaesthesia. Analgesia.
Exp. 3. (Upper extremity)	Anaesthesia. Analgesia, partial.	Retention of touch and painful sensibilities.
(Lower extremity)	Retention of sensibility to touch and pain.	Anaesthesia. Analgesia.
Exp. 4. (Upper extremity)	Retention of sensibility to touch and pain.	Retention of sense of touch Analgesia.
(Lower extremity)	Retention of sensibility to touch and pain.	Anaesthesia. Analgesia, partial. (Removed clip)
Exp. 5. (Upper extremity)	Retention of sensibility to touch and pain.	Retention of sense of touch Analgesia.
(Lower extremity)	Retention of sensibility to touch and pain.	Anaesthesia. Analgesia. (Complete).

The conclusions formed from a consideration of these experiments are: -

1. The sensory fibres from the lower limbs in monkeys decussate and pass up the opposite side of the spinal cord.
2. The sensory fibres from the upper limbs partly decussate and pass up the opposite side (pain and touch) and partly pass

up the same side (touch). [Plate IV.]

3. The retention in some monkeys of a sense of pressure on the otherwise anaesthetic limb, which is correctly localised.

VI.. Critical consideration of the results of experiments recorded by others, and those recorded in this paper, with notes on the occurrence of "Brown-Séquard's paralysis" in Man.

Briefly stated, the opposed opinions are: -

a. Retention of certain forms of sensation on the side opposite the hemisection, associated with diminution or abolition of certain forms of sensibility on the same side, (Mott, Horsley, Schäfer).

b. Retention of sensibility on the lower limbs on the side of the hemisection, abolition in the majority of cases of all forms on the opposite side, (Brown-Séquard, Ferrier).

It is not contended that all forms of sensation are abolished in the upper limb on the side opposite the lesion.

1. Dr. Mott pointed out (loc: cit:) that the clamp forceps were not removed from the paralysed limb but were invariably withdrawn by the animal when applied to the non-paralysed limb, and he was strengthened in the deduction which he made, as to a retention of sensation on the non-paralysed side, and a defect on the paralysed, when he put the animal under the anaesthetic influence of chloroform; on recovery from this he observed that the forceps were again pulled off the non-paralysed, and were left unheeded upon the paralysed side. Similar observations were made in some of the experiments recorded here, but with

the following additions. (a) When the forceps were applied to the skin of the paralysed leg, the monkey at once began to struggle and tried to move away from the source of irritation, but did not remove the forceps, at any rate during the earlier periods of observation. (b) When the clip was applied to the skin of the foot on the non-paralysed or anaesthetic side, the leg was at once drawn up and the clamp removed, but the monkey never exhibited any signs of discomfort. If, however, this leg were held by the observer, the animal never attempted to remove the forceps until the limb was set free and its movements unrestrained. In the fifth experiment, as long as the limb remained anaesthetic to all other forms of stimulation, no attempt was ever made to remove the forceps.

It therefore appeared, from the signs of discomfort and annoyance which were invariably observed when the clamp was applied to the paralysed leg, that the animal possessed sensibility to this form of painful stimulation. The fact of its not attempting to remove the clamp was probably due to a loss of correct cutaneous localisation on this side, its sensibility to painful pressure was certainly not diminished, while it always responded to ordinary tactile impressions. The removal of the clamp by some of the monkeys from the non-paralysed leg appeared at first to be due to an excessive reflex action, which was restrained when the limb was held. This view appeared to be negatived, when after holding the leg for a considerable time the clamp was withdrawn on setting the limb free. That an

abolition or defect of painful pressure sensibility existed on this side was shown by the fact that during the whole time the clamp remained applied, the animal never showed the slightest sign of discomfort or annoyance, but would continue eating an apple without appearing to be aware that anything was applied to its limb.

2. Dr. Mott has stated that when the feet of a monkey on which hemisection of the spinal cord has been performed, are dipped into hot water, or are touched with a test tube containing hot water, the non-paralysed leg is suddenly and at once removed from the irritation, while the paralysed is withdrawn but slowly. I believe the explanation of these phenomena is thus:The rapid withdrawal of the non-paralysed leg is essentially a reflex action, being unaccompanied by struggling, or any signs of discomfort. I have shown in the records of the experiments, that on applying a dull hot wire to the non-paralysed leg a sudden withdrawal of the limb took place (vide Exp. 5.), while it is a well-known fact, as pointed out in the experimental records, that the superficial reflexes are markedly exaggerated on the side opposite the lesion. The paralysed leg is only slowly withdrawn from the hot water, and that by struggling and movements of the body. To my mind this is indicative, not of diminished or delayed sensation, but of (a) motor paralysis preventing the rapid voluntary withdrawal of the leg, (b) diminished reflex action, which the experimental records show to be characteristic of the side of the lesion, and (c) the presence of

sensation as evidenced by the struggling and signs of discomfort which are apparent.

3. Gotch and Horsley have shown that when the sciatic nerve of a dog is stimulated, the excitatory effects in the cord are limited to a great extent to the side of the entering nerve, and that the effects are mainly dependent upon the unbroken integrity of particular columns of fibres on this side; and the facilities for ascending impressions by the columns of the cord are, in the order of least resistance, (a) posterior column of the same side, (b) lateral column of the same side, and (c) posterior column of the opposite side, the lateral column of the opposite side offering apparently no facility to the passage of upward impulses.

It is at least hazardous to assume that the paths which offer least resistance to magnetic currents are also those by which common sensation is conveyed by the spinal cord. It has however, been held by some (eg Schiff) that tactile impressions are conveyed by well defined paths, while painful and other severe impressions pass by paths more widely distributed.

It appears to me that the results of experiments of this nature are mainly dependent upon the physical characters of the tissues which are under investigation; and as the arrangements necessary for their performance are detailed, severe and prolonged, important alterations may occur in the structures under consideration. And, further, as has been already indicated, there are probably many other afferent impressions than those

subserving common sensibility from the skin, viz: visceral, muscular, vascular, etc. It is impossible therefore, by such a method to differentiate the paths of sensation proper from those which are afferent.

4. The presence of tracts, which degenerate upwards on the same side as the lesion, furnish no criterion that they are paths of common sensation for that side. The ascending tracts will be discussed more in detail later on and their physiological relations more closely considered. At present it may be simply stated that they are indicative of centripetally conducting fibres whose trophic centre is obtained in segments of the cord below the lesion. The possibility of some of these tracts or of certain of their fibres having a crossed origin, ought not to be disregarded.

5. The consideration of cases of "Brown-Séquard's paralysis" in the human subject, is mainly corroborative of the experiments just recorded. There is a tendency in the minds of those who rely on experimental methods, to overlook the form of evidence supplied by clinical observation, or to minimise its usefulness. But the facts remain undisputed, that a unilateral lesion of the spinal cord produced by a stab in the back, or by disease limited to one half of the cord, and verified by post-mortem examination, is productive of paralysis on the side of the lesion, and anaesthesia on the opposite side. Of 59 cases of this paralysis which I have collected, in all the sense of touch was present on the paralysed limb, in some indeed exhibiting a hyperaesthetic condition; while on the limb opposite the lesion, in the

vast majority of cases tactile sensibility was either abolished or defective. The sensibility to pain was similar to tactile sensibility. In some of the cases there was hyperaesthesia to pricking and pinching, in others the sensibility was normal on the paralysed lower extremity. On the opposite limb there was either analgesia or defective recognition of painful stimuli. The sense of cutaneous localisation does not seem to have received as much attention as it deserves. Brown-Séquard believed that there existed perfect knowledge of the localisation of impressions on the paralysed limb, while there was loss or great diminution of this faculty on the anaesthetic side. The experiments indicate that with the restitution of sensation on the side opposite the lesion, at first apparently as mere contact (vide Chap.II) the sense of localisation also returns, and painful impressions such as are produced by pricking, pinching, and the clamp, although at first not occasioning any feeling of discomfort are accurately localised. On the paralysed leg, although all forms of sensation were localised, yet the clamp was never removed, although considerable discomfort and annoyance was caused by its presence.

6. Brown-Séquard's view of the existence of special conductors for the different kinds of sensory impressions and of different paths for their conduction in the cord, was based upon clinical evidence in Man. There are cases of disease of the spinal cord on record in which with defective sensibility to touch and pain, there co-existed complete loss of the sense of temperature (1);

(1) Revillout. Gaz. des Hôpitaux. 1880 p.585.

or again, tactile sensibility has been present, while painful and temperature sensibilities were in abeyance (1). The existence of specific conducting paths opens up a wide and important question. That one form of common sensation may be abolished while another is retained, probably shows that fibres may be differently affected by disease in their conducting power, or in the receptivity of their end-organs for external impressions (Ferrier). This seems to be a more favourable view than that of regarding spinal conducting paths in different portions of the cord, and it appears to be supported by the facts of restitition of sensation. Briefly, the experiments showed that, with the doubtful exception of the first experiment, all forms of sensibility were contemporaneously restored.

The instances which have been mentioned as illustrative of the presence of one form of sensation, while others were lost, show a close relationship between the sensibilities of pain and temperature; I have not been able to find a case in which the sense of touch was absent, while those of pain and temperature remained (2). I submit that the experiments recorded in this paper, are opposed to the view that there exist in the spinal cord special conducting paths for the diverse kinds of sensory impressions. The synchronous return of both kinds of common sensation after hemisection of the cord of monkeys, distinctly

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(1) Bernhardt. Arch. f. Psychiatrie. 1874 p.227.
(2) Cases of Syringomyelia show very extraordinary defects of sensation, which cannot be explained by this hypothesis. It is to be observed in these cases that the disturbances of sensation are due to interference with the nerve roots and not to the conducting paths in the cord (Ferrier).

favours the unitary theory of sensory conduction in these animals.

VII. The degenerations which follow hemisection of the spinal cord.

I have made a systematic examination of the tracts degenerating upwards and downwards, secondary to the lesions of the spinal cord, and illustrative of the already recorded experiments. My observations in this field have brought out important facts in connection with the tracts which degenerate upwards from a lesion of the spinal cord.

1. Descending degenerations.

These degenerations were limited to the side of the hemisection, if this was of a perfectly unilateral nature. If the opposite side of the spinal cord had been injured either during the performance of the operation or from "traumatic degeneration" subsequently to it, I observed a slight amount of secondary sclerosis in the direct pyramidal tract on the side opposite the lesion. I may state that this applies also to the ascending degenerations to be shortly considered: In this case it is the median portion of the column of Goll which showed a linear sclerosis.

The crossed pyramidal tract. I am unable to add anything to what is already known regarding this tract. I can confirm Sherrington's observation, that in the monkey the tract is unequally divided into two portions by the direct cerebellar bundle of fibres in the cervical region. I have been unable to

detect the so-called "recrossed fibres" on the opposite side described by this observer. The formation of a cap to the crossed pyramidal bundle by a strand of fibres passing outwards towards the direct cerebellar tract in the lower dorsal region and probably coming from the cells of Clarke's column, and separating it from the posterior horn of grey matter is well seen in my sections.

(Plates V + VI.)

The direct pyramidal tract. I have traced this strand of fibres considerably lower down in the cord than is given in the text-books. I have obtained distinct sclerosis in this region as low as the level of the roots of the sacral nerves. As a rule it is distinctly marked to the lower end of the lumbar enlargement. It has been stated by Mott that this sclerosis is

due to interruption of vertical commissural fibres between the cells of the anterior horns at different levels.

(Plate VI.)

The "comma-shaped" tract of the posterior column. In one case (Experiment 2.) a descending area of degeneration was observed in the posterior root zone on the side of the hemisection. It occupies the position or direction of certain of the entering posterior nerve roots. I have traced it four segments below the lesion.

The exact nature of this tract is still doubtful, but I think there can be no doubt that it is due to the downward direction of certain fibres of the posterior roots or of their "collaterals" before they either pass upwards or enter the grey matter.

The tract is well illustrated in a human cord in my possession, following a crush of the spinal column.

(Plate VII)

The explanation of its presence in some cases and not in others is to be found probably in the fact, that in the former series the posterior nerve roots have been themselves injured, while in the latter the injury has taken place between two sets of nerve roots. Mott (op. cit. p.23) has stated that the fibres of this tract may possibly be vertical commissural connections between the cells of Clarke's column at different levels. I think that its inconstant presence ought to be remembered when considering the nature of this tract.

2. Ascending degenerations.

The examination of these tracts is of considerable

importance and the determination of their proximal extremities valuable, as they have been regarded by many observers as forming individually or together the paths of sensation from the trunk and extremities.

The direct cerebellar tract.

(Plates VIII to XIII)

My observations are mainly confirmatory of those already made by other observers. (Kölliker, Mott). The origin of the fibres of this tract in the lower dorsal and upper lumbar regions, probably from the cells of Clarke's column, its position ventral to the posterior horn of grey matter in the cord, and finally its passage into the restiform body and cerebellum are all distinctly observed.

That this tract is afferent in function has long been

known, and its connection with the cells of Clarke's column suggested that it was a path of communication between the viscera and the cerebellum.

Its essentially centripetal nature receives confirmation in a series of sections of the spinal cord in my possession, following extirpation of the left lobe of the cerebellum. In these specimens there is no evidence of any alteration in the fibres of the direct cerebellar tract, which stands out clearly in an atrophied restiform body.

The emission by the cerebellum of an efferent strand of fibres is probable and Marchi has described such a tract in the antero-lateral region of the spinal cord. The direct cerebellar tract therefore appears to be entirely of an afferent nature.

The antero-lateral ascending tract. (Gowers).

(Plates VIII to XIII.)

It is this tract to which I wish specially to refer. It was regarded by Dr. Gowers, who originally described it, (1) as a path for the transmission of painful impressions. Its proximal termination, however, in the medulla oblongata, and a want of evidence as to its further course somewhat militated against this view. It was not until Loewenthal (2) in 1885 described its proximal extension into the cerebellum, by way of the superior cerebellar peduncle, that its sensory function was definitely disputed. As far as I have been able to ascertain, Loewenthal's observation has not received confirmation, at any rate by workers in this country.

The series of sections of the spinal cord amd medulla oblongata, which I have made, after hemisection and complete transverse division of the spinal cord, corroborate Loewenthal's observation.

In the upper cervical region the antero-lateral and the direct cerebellar tracts form one continuous band of degeneration, extending from the posterior horn round to the anterior nerve roots. As one passes up, however, towards the region of the olive, the two tracts, which were separate in the cord below, again part from each other, and at the level of the mid-olive, the antero-lateral tract occupies a position just dorsal to this structure and amongst the external arciform fibres, while the direct cerebellar bundle has passed up into the

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(1) It was many years before figured by Dr. Bastian. Med. Chir. Trans. 1865.
(2) Loewenthal. Rev. de Méd. de la Suisse Romande. 1885. p.511

restiform body. Still more proximally beyond the entrance of the restiform tract into the cerebellum, and with the appearance of the superior cerebellar peduncle in transverse section, two areas of degeneration are observed, a ventral accupying a small region anterior to the issuing roots of the eighth nerve; and a dorsal, lying in the white fibres of the medullary velum which covers the brachium conjunctivum. In sections still further towards the mid-brain, these two areas of sclerosis are found to approach each other, and eventually to fuse. Although my sections do not show actually degeneration in the cerebellum, I have been able to trace the sclerosed area towards the inferior vermiform process.(+)In a series of sections which I have illustrating the degenerations following removal of a cerebellar hemisphere, the brachium conjunctivum on the side of the extirpation is completely sclerosed, while the medullary velum, which contains this ascending tract presents a normal appearance, indicating that the tract is essentially afferent in function.

(+) A small area of degeneration has since been pointed out to me in the lingula of the Inferior worm in one of my sections which probably represents the continuation of this tract.

That the area of degeneration lying upon the brachium conjunctivum in the velum medullare of the superior cerebellar peduncle, is the upward continuation of the antero-lateral tract, is concluded by a process of exclusion, which is justified by some observations of Dr. Mott's to be immediately narrated.

Section and hemisection of the spinal cord were performed in the mid-dorsal regions of the animals from which my sections were taken. These observations therefore point to long fibres passing from the lower regions of the spinal cord to the cerebellum, by the way of the superior cerebellar peduncles, an observation which I do not think has been previously pointed out.

At a meeting of the Neurological Society of London on March 17th 1892, Drs. Mott and Tooth showed a series of sections also confirmatory of Loewenthal's observations. Dr. Mott had divided the antero-lateral region of the spinal cord in the upper cervical region, and had traced by means of Marchi's method, degenerated fibres through the medulla oblongata to the superior cerebellar peduncle and finally into the vermiform process of the cerebellum. Dr. Tooth, on the other hand, traced a similar condition by the Weigert-Pal staining method after division of the lateral region up the spinal cord between the first cervical nerve and the decussation of the pyramids.

As the result of Loewenthal's original observations and its subsequent confirmation by Drs. Mott and Tooth and myself, I have concluded <u>that the antero-lateral tract is a cerebellar tract</u>, whose functions we do not yet know. That it is not a path of sensation appears sufficiently evident from the facts just

narrated.(I) [Plate XIII]

The postero-median column.(Plates VIII to XI.)

When a hemisection is made of the spinal cord in the lower dorsal region, the area of sclerosis occupying this column in the upper cervical region is of considerably less superficial extent than the area of degeneration following a hemisection of the upper portion of the cervical enlargement. This results from the fact that many more fibres are cut across by the high section, than by the one lower down. Following division of several of the posterior nerve roots of the lumbar plexus between the ganglion spinale and the spinal cord, one observes at the level of the operation a degeneration of fibres in the posterior root zone; a few segments higher up this area is found to have passed towards the middle line and to occupy an area midway between the posterior horn and the posterior median septum . The number of the degenerated fibres traced upwards in this way is considerably less than what is observed in the posterior root zone at the level of the operation, showing that many of the root fibres have taken another course, viz: into the grey matter of the posterior horn.

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(1) Division of the antero-lateral region of the spinal cord does not occasion any loss of sensation in the parts below the lesion (Mott).

Tracing this degeneration still proximally one finds it continually approaching the inner or posterior corner of the postero-median column; and it has been found as a result of division of the posterior roots of the various segments of the cord, that the direct fibres of the lowest nerves occupy a postero-median position, while those of the higher nerves occupy a postero-lateral position in the columns of Goll.

These columns as is well known, end in the nuclei graciles of the medulla oblongata. Degeneration is not tracable beyond the nuclei, nor is one able to detect any atrophy or shrinking of the posterior pyramids, restiform body, arciform fibres or fillet, which are the proximal continuations of the postero-median columns.

VIII. The afferent tracts in the Spinal Cord .

The description of the secondary degenerations following hemisection of the spinal cord showed, that these were entirely limited to the side of the section, if the lesion was unilateral while small areas of degeneration may be observed on the opposite side either as a result of implication of nerve tissue at the seat of the lesion from "traumatic" effects, or as a result of implication of the nerve roots in the fibrous tissue at the seat of the operation. It has been demonstrated that of three ascending tracts which are invariably sclerosed after hemisection of the spinal cord, one passes directly to the cerebellum of the same side, another ends in the medulla oblongata and the cerebellum; while the third which also ends in the medulla , has connections with the structures related to the coordinating mechanism of the body.

1. The direct cerebellar tract, which receives its fibres from the cells of Clark's column from the 9th to the 11th dorsal nerves, occupies a definite position in the spinal cord and finally passes into the restiform body to end in the nucleus dentatus (Löwenthal) the grey matter of the inferior vermiform process (Flechsig) or of the superior vermiform process (V.Monakow). As no descending change is visible in this tract after removal of a cerebellar hemisphere, it can safely be surmised to be of purely afferent nature and as destruction of whole or part of this organ produces no alteration in the sphere

of common sensation (Luciani) (+) this tract may be set aside as not being of a sensory conducting nature.

2. The ascending antero-lateral tract arises low down in the lumbar region but has not been found to undergo degeneration after section of the posterior nerve roots of the lumbar enlargement on the same side but only after division of the cord itself. It has not yet been shewn whether it has any direct relationship with cells in the grey matter of the opposite side. Although in the upper portion of the cervical region this tract and the direct crerbellar often form one continuous band of degeneration, in the middle portion of the medulla they again become separate and the more anterior can be readily traced as a separate strand lying behind the olive.

From the observations which I have just recorded on this tract and from those of Bechterew (1) who stated that the developing tract distinctly ends in the nucleus lateralis and of Von Monakow (2) who found atrophy of the cells of this nucleus in association with absence of development of this tract following hemisection of the spinal cord of a new-born rabbit, one can definitely infer that the antero-lateral tract also is not a path by which common sensation is transmitted to the cerebrum.

3. The fibres of the column of Goll end in the nucleus gracilis which is in close relation with, on one hand the restiform body and on the other with the interolivary layer of the opposite side and the fillet.

(+) Experiments on the cerebellum conducted by Dr. Ferrier and myself corroborate this observation.

Does experiment throw any light upon the functions of this column of fibres? Ferrier has shown that section of the columns of Goll in a monkey dóes not produce any loss of cutaneous sensibility while temporary ataxic symptoms ensued. Schiff has stated that their division is followed by a loss of tactile sensibility. Gotch and Horsley (op.cit) have also divided the posterior columns in Cats; these observers found that "the water test" showed diminished sensibility in both hind feet , since the animal could be placed with its hind paws in water without exhibiting any movement of withdrawal.(+) The effects of disease are not corroborative of this latter view. In a rare condition known as Primary Sclerosis of the columns of Goll, Pierret (3) Camuset (4) and Ross (5) have shown that marked disorders of equilibration are symptomatic of the affection; a slight loss of cutaneous sensibility was observed in the lower limbs in these cases, but the autopsy showed that the posterior root zones were partially affected in the lower portions of the cord.

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(1) Bechterew. Mentioned by Tooth - "Secondary degeneration": p.64.
(2) Von Monakow - Arch. für Psychiatrie. 1883.p.1.
(3) Pierret - Arch. de Physiologie. 1873.p.74.
(4) Camuset - Le progrès Médical. XII.1884.p.1008.
(5) Ross - Brain 1886.p.34.
(+) Gotch & Horsley - op.cit.

In considering the question of the transmission of sensory impressions by the posterior columns of the cord, a sharp line of demarcation has to be drawn between the posterior root zones and the postero-internal columns of Goll. As is well known all the fibres of the posterior nerve roots enter the cord by the posterior root zones. A certain number of these fibres pass directly into the columns of Goll while a large number dip into the grey matter of the posterior horn. Of the latter some pass to the cells of Clarke's column and thence to the direct cerebellar tract (Flechsig, Lenhossek, Edinger, and others). Others pass to the region of the anterior horn while, yet others ~~still~~ pass to the opposite side of the cord by the grey commissure (Kölliker and others) My own specimens amply corroborate these views. Destruction of the root zones either by experiment or by disease (as occurs in tabes dorsalis) occasions defects of sensibility in the corresponding segment of the body, but not in the regions lower down, showing that these tracts are not conveying sensory impressions from lower to higher parts. I submit that the fibres which pass directly into the columns of Goll are afferent and convey impressions in connection with equilibration and co-ordination of movements; while of those, which pass into the grey matter, some are the sensory fibres from corresponding segments of the body, whose function is arrested when the opposite half of the spinal cord is divided above their entrance, as well as of all segemnts below.

There is therefore not much evidence in favour of the

columns of Goll being centripetal paths for cutaneous sensibility ; while their proximal continuations the posterior pyramids the restiform bodies, the internal arciform fibres, interolivary layer and fillet present even less proof of this.

In this connection I will refer to an experiment which I have recently performed on a monkey. By means of the galvanocautery, I destroyed the posterior pyramid nucleus on one side and observed the effects. The most marked feature was a tendency to fall over towards the side of the lesion, associated with slight disorder of equilibration ; the general appearance of the animal was like that observed after injury to a partial destruction of the cerebellum. The monkey for two days after the operation lay upon its left side as if suffering from vertigo. No affection of sensation was detected. This experiment has since been repeated by Dr. Ferrier and myself with similar results.

Spitzka (1) in a case of haemorrhage into the pons Varolii traced ascending and descending degenerations in the fillet from the seat of the lesion. Vejas (2) found atrophy of the interolivary layer on one side after destruction of the nuclei of Goll and Burdach on the opposite side, the connection between the two being by the internal arciform fibres, (+)

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(1) Spitzka. Amer. Journal of Neurology.Nov. 1883.
(2) Vejas. Arch. f. Psychiatrie. Bd.XVI. p.200.
(+) I have seen sections showing degeneration of the internal arciform fibres and opposite interolivary layer after destruction of the nucleus of Goll - Private communication by Dr. H.Tooth.

P.Meyer (1) recorded a case of focal lesion of the internal arciform fibres, with degeneration in the fillet on the opposite side ; Von Monakow (2) while performing an operation on the occipital lobe of a new born cat wounded the pons Varolii at the point of exit of the fifth nerve ; when the animal was killed six months after this operation, there was observed almost total disappearance of the fillet and degeneration of the interolivary layer on the same side, while on the opposite side there was atrophy of the internal arciform fibres and of the nuclei of Goll and Burdach. Edinger (3) has confirmed these observations by the developmental method.

Experimental lesions upon the fillet with a view to ascertain the symptoms which follow a break in its continuity are difficult to perform and impossible without interfering with other important structures, but a few cases of disease, of this strand of fibres in man are on record. Leyden (4) records a case of softening of the interolivary layer, in which the symptom was marked ataxy, so that the patient could neither feed himself nor walk nor stand. Sensibility to touch and pain was perfectly natural in all parts of the body. In Spitzka's case, previously alluded to, with marked ataxy of the limbs on the right side of the body, there was slight disturbance

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(1) P.Meyer: Arch. f. Psychiatrie. Bd.XVII.Hft 1.
(2) Von Monakow. Corresp. Blatt. f. Schweizer Aerzte. 1884. Neurol. Centralbl. 1885. No. 12.
(3) Edinger. Neurol. Centralbl. 1885. No. 4.
(4) Leyden. Arch. für Psychiatrie. VII. p. 57

of tactile sensibility only, while the lesion was found to involve the whole area of the fillet on one side with a slight implication of the adjoining formatio reticularis. Wernicke (+) describes a tumour implicating the floor of the fourth ventricle, the fillet being unaffected. In this case there was no disturbance of equilibration or no ataxy.

I have endeavoured to show that there is not sufficient evidence for regarding the tracts which degenerate upwards as paths of common sensation.

IX. The probable paths of the fibres subserving common sensibility.

A difficulty in the way of accepting the theory of the complete decussation of the sensory fibres consists in the relatively small number of fibres which are found crossing the middle line of the spinal cord.

I have therefore undertaken a series of examinations of the spinal cords of monkeys with the view of ascertaining by what means transmission of impressions may be carried from one side of the cord to the other.

An examination of a transverse section of the spinal cord shows, in the region of the central canal, two so-called commissures ; one lying in front of the canal at the bottom of

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(+) Wernicke. Arch. für Psychiatrie.VII.p.513.

the anterior median fissure and formed of large medullated fibres passing from the anterior column of one side to the anterior horn of the opposite side. This the anterior or white commissure is actually a decussation and would be more correctly called by that term. Immediately in front of and behind the central canal is the posterior or grey commissure, which is distinctly divided into two portions by the canal and which may be respectively called the anterior and posterior grey commissures. Through the grey commissure fibres pass from one side of the cord to the other, but they are not readily detected ;
1) although many are medullated they are very delicate ;
2) they do not retain the Weigert-haematoxylon stain well,
3) many of the fibres are non-medullated, special methods of staining being necessary to discover them, and 4) they are not detected by the degenerative method.

The fibres of the posterior grey commissure mainly pass between the grey matter of the posterior horns, while those of the anterior grey commissure pass transversely across between the grey crescents.

Edinger (+) has endeavoured to explain this decussation by stating that a large number of fibres pass from the base of the posterior horns by the anterior commissure to the anterior root zone of the opposite side. He has found this well marked in fishes and amphibians. In man it is much more difficult to demonstrate.

(+) Edinger. "Einiges vom Verlauf der Gefühlsbahnen im Centralen Nervensystem." Frankfurt a/M.1890

I believe that there is a sufficient anatomical foundation for the complete decussation of the sensory fibres. Golgi's method of staining, which has led to such good results in his hands and in those of Ramón-y-Cajal and Kölliker, demonstrates the large decussation of fibres and "collaterals" of nerve fibres which is taking place all along the cord. This method has shewn that it is unnecessary that a fibre should be in direct continuity with a nerve cell so as to transmit impressions, contact alone is sufficient. By this means the grey matter of the spinal cord and the formatio reticularis grisea of the medulla oblongata afford a convenient area for the passage of sensory impressions.

I have shown that the only portions of the spinal cord which do not degenerate either upwards or downwards are the grey matter itself and the white matter lying in close relation to it. All along the cord fibres are to be observed passing from the grey matter to the adjacent white matter, apparently having no connection with the cells of the anterior horns. That many of these fibres pass into the adjacent white matter or are the "collaterals" of the fibres of this layer, I have no reason to doubt ; and that they are the means of conveying sensory impressions from one side of the cord to the other is highly probable.

The white matter which lies in close relation with the antero-lateral aspects of the grey crescents (the lateral limiting layer and mixed zone of Flechsig) are found to

myelinate in foetuses 25-28 c.m. long, there being no other part of the spinal cord so formed with the exception of the anterior ground bundle and the posterior root zones. The anterior ground bundles pass backwards at the lower end of the medulla with the central canal and form the posterior longitudinal fasciculi ; these two structures form, in all probability, commissural strands of fibres for the cells of the anterior horns and motor cranial nerve nuclei respectively. The lateral limiting layer and mixed zone are the only regions in the spinal cord in direct continuation with the formatio reticularis grisea of the medulla oblongata. This strand of nerve fibres is found to increase in size from below upwards and at the level of the first cervical nerve enters into the formation of the processus reticularis. The direct continuation of the lateral portion of the formatio reticularis with the lateral limiting layer has been insisted upon by Flechsig (Die Leitungsbahnen etc.)

I will conclude by stating that the paths by which sensory impressions may be conveyed through the medulla spinalis and oblongata.

1. By the fibres of the posterior root zone which pass directly into the grey matter of the posterior horn.

2. By fibres from the posterior horn which cross the middle line in front of and behind the central canal.

3. By fibres in the grey matter of the opposite side or by fibres in the white matter lying in close relation with the lateral aspect of the grey crescent.

4. By the fibres of the formatio reticularis grisea.

Postscriptum. The experimental and anatomical observations recorded in the preceding chapter upon the paths of sensation in the spinal cord and medulla oblongata, are only referable to the trunk and extremities ; the paths, by which sensory impressions are conveyed from the eye, the face and the mucous membranes supplied by the fifth nerve, are at present the subject of investigation.

CHAPTER II.

ON THE RESTITUTION OF FUNCTION IN THE SPINAL CORD.

C H A P T E R II.

ON THE RESTITUTION OF FUNCTION IN THE SPINAL CORD.

I. Prefatory note.

During the course of the experiments upon hemisection of the spinal cord detailed in the preceding chapter, it was observed that the extremities which had been paralysed or which had been rendered anaesthetic, invariably recovered both the power of movement and the perception of sensory impressions; and that the order of the return of movement was from general to special movements, while the muscles which remained unaffected were those associated in bilateral movements.

As the position of the lesion was in every case localised in the spinal cord, a consideration of these experiments throws some light on the method by which this structure regains its functions. Before detailing the observations, an historical resume is given of what is already known regarding regeneration and the return of function in the cord.

II. Short historical digest.

Since the original work of Brown-Sequard (1) in 1849 on regeneration in the spinal cord, a good deal of attention has

(1) Brown Sequard. Gazette Medicale, 1849, 1850, and 1851.

been given to the subject from the histological point of view, and researches have been carried out upon animals throughout the vertebrate scale. Masius and Vandair (1) (1870) removed portions of the spinal cord from frogs, 1-2 c.m. long. At the end of a month volition and sensation reappeared, motor power returning at a somewhat earlier date than sensation. In the cicatrix which joined the two ends of the divided cord, they found ganglion cells and nerve fibres, the former resembling those found in other parts of the nervous system, the latter similar to the fibres of Remak. Schiefferdecker (vide infra) in criticising these observations pointedly remarks that connective tissue corpuscles might readily be mistaken for ganglion cells. H. Müller (2) (1864) performed similar experiments on Tritons, but he was unable to detect any return of voluntary movement, or any evidence of regenerated nerve tissue in the cicatrix.

Brown-Séquard's (3) earlier experiments (1849) were performed on pigeons. He found that movements returned after some months, but that they remained defective considerably longer than sensation. In the following year (1850) he made a complete transverse section of the spinal cord of an adult pigeon. After

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(1) Masius and Vandair. Mémoires Couronnés &c. XXI, 1870. As I have been unable to obtain their original work, I am unable to state on what grounds they based their belief in the return of motion and sensation - Abstract in the Monthly Microscopical Journal, May 1870.

(2) H. Müller. Canstatt's Jahresbericht, 1864 - I, p.53.

(3) Brown-Sequard. Gazette Medicale, 1849, 1850, and 1851.

three months nerve cells and fibres were found in the cicatrix, but this regeneration was not sufficient to permit of a return of movement and sensation. He especially noted that reflex movements were active around the anus. In 1851 he had greater success, for a pigeon which was completely paralysed through a transverse section of its spinal cord, began to exhibit movements after three months, when sensibility also reappeared. In seven months it progressed feebly, in twelve it could run, and in fifteen it was apparently normal.

Dentan made transverse sections of the spinal cord of (1) puppies four or five days old. Those that lived showed more or less complete regeneration of the spinal cord, but an analysis of the phenomena on which he based his statement reveals the error into which he fell. His chief mistake was to regard all movements of the hind part of the body as voluntary. For instance, he states as evidence of the return of voluntary power, that the urine and faeces were passed at regular intervals; that return of movement was observed one week after 6-7 mm. of the spinal cord had been removed; and that a dog could stand and even move a short distance forwards after its cord had been cut across in the dorsal region. These observations are no doubt correct, but the inference that they are indicative of the return of volition is entirely erroneous. The consideration of

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(1) Dentan. Inaug - Dissertation. Berne 1873.

Dentan's work alone would be highly injurious to a proper understanding of this subject. He has been unable to distinguish between reflex and volitional actions. Anyone who has studied the results of division of the spinal cord in animals, or of the effects of injury and disease in man, cannot fail to have been struck with the nature of the movements which ensue. But it is the error of a mere novice both in clinical and experimental work to confuse reflex and volitional movements, at any rate in the higher mammals. In frogs, as is well known, reflex movements are well coordinated, and to all appearances are purposive in character; and the movements of scratching evoked on tickling the abdomen of a dog are of a like nature. But to argue the presence or return of volition, because the urine and faeces are passed at regular intervals is at any rate the mistake of an inexperienced observer.

I have observed movements of the tail of a monkey whose cord had been carefully divided, apparently caused by the presence of faeces in the rectum. The exaggeration both of the superficial and deep reflexes which occurs after division of the spinal cord is well known; while after hemisection of the cord, with diminution or even abolition of the reflexes on the side of the lesion there is marked exaggeration, mainly of the skin reflexes, on the opposite side; and this rule applies also where the cord is hemisected for a second time on the other side; on the side opposite the lesion there is exaggeration of

the cutaneous reflexes.

An observation made by Gotch and Horsley (op. supra cit.) shows well the extreme excitability of the spinal cord to reflex action. They observed that after complete division of the cord, or even after removal of a piece 1 cm. long in the mid-dorsal region, mechanical irritation of the sciatic nerve caused not merely movement of the upper limbs but also of the head. The reflex in the upper portion of the body was aroused by dragging upon the nerves of the upper portion of the cord caused by the reflex movements in the lower limbs.

Naunyn and Eichhorst (1) (1874) also experimented on young dogs and rabbits. The latter observer gives no indication of a real union between the ends of the divided cord, for although nerve fibres were found in the cicatrix, they did not pass through or unite the ends of the cord.

Schiefferdecker (2) (1876) who also used dogs for his experiments found no evidence of physiological return of motor power even up to 397 days after the operation. The reflexes were in all cases exaggerated. Not a trace of nerve fibre was found in the Scar tissue, nor even a nerve fibre passing from the end of the divided cord into the cicatrix, which consisted entirely of a fine fibrous network.

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(1) Naunyn and Eichhorst. Arch. of Experim. Pathol. u. Pharmacol. Bd. II, 1874.
(2) Schiefferdecker. Virchow's Archiv. Vol.67, 1876.

Francesco (1), who is the most recent worker on this subject (1891) produced complete and lasting paralysis of the hind limbs after transverse section of the spinal cord in tritons, lizards, frogs, pigeons, and dogs. Frogs and pigeons, which are the only animals presenting any definite signs of return of movements show, as is well known, coordinated reflex movements which may be mistaken for volition.

It would appear from a consideration of the above facts, that return of voluntary movements resulting from regeneration of the fibres of the spinal cord does not occur. My own observations on monkeys entirely accord with these views.

After complete transverse division of the spinal cord in monkeys there was no evidence of any return of voluntary movements (as long as) the animals remained alive, amounting in one instance to four months, while in the monkeys where hemisection of the spinal cord was performed, movement and sensation began to return a short time after the operation. This restitution of function was brought about by the uninjured half of the cord taking on the functions of that which was divided, and by the opening up of hitherto unused, or little used, decussating strands of nerve fibres.

After transverse division of the spinal cord, two conditions were observed, at the seat of the lesion at the post

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(1) Francesco. La Psychiatria, 1891, VIII. (Neurol. Centralb. p.392, 1891.)

mortem examination. In one instance, the space between the ends of the divided cord was filled in with cicatricial material, which rendered possible the removal of the cord in one piece. In other instances the divided ends of the cord were separated by a distance of 1/3-1/2 inch, the gap so formed presenting no indication of any cicatricial material. After hemisection of the spinal cord, the space made by the incision in every instance presented a fibrous cicatrix.

A microscopical examination of the cicatrix showed that it was formed of white fibrous tissue. Staining by means of the Weigert-Pal method failed to reveal the existence of any regenerating nerve fibres.

III. Experimental Record.

The experiments on which the following observations are based, are the same as were used for the observations on cutaneous sensibility, and have been already recorded in the first chapter. The observations on restitution were carried on pari passu with those on sensation. As it was impossible to record the observations on sensation without reference to the restitution of function, the facts bearing on this portion of the subject are only mentioned here in abstract, while the restitution of the motor functions are recorded in this chapter for the first time.

Experiment 1. (vide also p. 10). First operation - Division of the right side of the spinal cord at the level of the ninth dorsal nerve roots.

1st day. Paralysis of the right lower limb; anaesthesia of the left.

3rd day. Animal recognised without discomfort when touched with a dull hot wire on the left knee.

5th day. Animal recognised pricking with a pin, and touching with a dull hot wire on the left lower limb.

10th day. Painful impressions were perceived, but less readily than in right side.

24th day. Flexion observed at the right hip joint.

38th day. Flexion and extension observed at the right hip joint; perception of painful impressions (heat and pricking) in left lower limb.

53rd day. Flexion and extension at the right hip joint; flexion and extension at right knee joint; well-marked drop foot. Tactile and painful impressions readily recognised on left lower limb.

68th day. Second operation: - Section of the left side of the spinal cord at the level of the sixth dorsal nerve roots. Complete paralysis and anaesthesia of both lower limbs.

113th day. Complete paralysis and anaesthesia of both lower limbs.

P.S. The tardy return of tactile sensibility in this experiment deserves special notice. The notes indicated that for many days much doubt existed regarding the sensibility of the non-paralys-

ed limb, so that it is not improbable that the sense of touch returned considerably earlier than is noted here.

Experiment 2. (vide also p. 14). Section of the left side of the spinal cord at the level of the seventh dorsal nerve roots.

1st day. Paralysis of the left lower limb, anaesthesia of the right.

6th day. Perception of tactile and painful impressions on the right lower limb, apparently only as contact, for there were no signs of undue discomfort on pricking.

22nd day. Flexion at the left hip joint, followed shortly by extension at that joint.

50th to 60th days. Movements at the left hip joint; flexion with extension of left knee joint; persistance of left-sided drop foot. Tactile and painful stimuli were recognised on the right side, but the response was obtuse, and a greater severity of stimulation was required.

Experiment 3. (vide also p. 16) Section of the left side of the spinal cord between the third and fourth cervical nerves.

1st day. Paralysis of left arm and leg; analgesia of the right leg (sensibility to touch not definitely determined); obtuseness of sensibility of the left arm. The left leg and the right arm normal as regards sensation.

7th day. Recognition of tactile and painful stimuli on the

right flank and buttock, and also in the leg and foot. The blunting of the sensibility on the left arm is less marked.

13th day. Flexion at the left hip joint.

29th day. Flexion and extension at the left hip joint and slightly at the left knee joint.

55th day. Considerable improvement in the movements of the left leg; some movement at the left shoulder joint. Perception of sensation on the left arm considerably improved.

106th day. Movements of left leg almost completely restored; slight movements of the toes; slight left drop foot. The left elbow can be flexed and extended and raised as high as the shoulder; well marked left wrist drop. Perception of sensation normal on the right leg, obtuse on the left arm.

In the fourth experiment the monkey did not live sufficiently long to reveal any restitution of function.

Experiment 5. (vide also p.21) Section of the left side of the spinal cord between the fourth and fifth cervical nerves.

1st day. Paralysis of the left arm and leg; anaesthesia and analgesia of the right lower limb; normal perception of sensory stimuli on the left lower limb; analgesia of the right fore limb with perception of tactile impressions; perception of painful impressions on the left fore limb, sensibility to touch remaining doubtful.

3rd day. All the symptoms as before, with the exception that tactile impressions were recognised on the left fore limb.

16th day. Tactile and painful stimuli recognised on the right hip and thigh, apparently as a feeling of contact only, as there was no evidence of discomfort.

20th day. Remains in statu; no evidence of any return of movement in the left limbs, they are becoming slightly contracted and rigid.

Between the 20th and 40th days the monkey improved in general condition, being able to crawl along the floor, but it was not able to move the left arm at all, and only the left hip to a very slight extent.

IV. Consideration of the Restitution of Function.

These experiments indicate variations in the duration of the symptoms following hemisection of the spinal cord in monkeys and in the occurrence of Restitution.

The results are briefly summarised in the following table, which shows readily the order and date of the restoration of sensation and motion.

	Exp.1.	Exp.2.	Exp.3.	Exp.5.	
Sensation					
Lower limbs.					
Pain (heat).	3rd day.	6th day.	7th day.	16th day.	
Pain (prick)	5th day.	6th day.	7th day.	16th day.	
Touch.	?	6th day.	7th day.	16th day.	(above knee only)
Upper limbs. Pain)					
)	- - -	- - -	never entirely lost.		
Touch)					

Motion.		Exp.1.	Exp.2.	Exp.3.	Exp.5.
Hip-joint.	Flexion. (Extension a few days later).	24th day	22nd day	13th day	There was no return of movement up till death 40 days after operation.
Knee-joint.	Flexion. (Extension a few days later.)	30th day	30th day	20th day	
Ankle-joint		-----	-----	by 50th day	
Toes.		-----	-----	by 100th day	
Shoulder-joint		-----	-----	by 55th day	
Elbow-joint.		-----	-----	by 70th day	
Wrist.		-----	-----	-----	

The nature of the lesion was similar in each of the experiments, and the operation was performed under similar conditions (antiseptic and anaesthetic, etc.). The variations in the time of restitution therefore depend upon individual peculiarities, such as age, etc., and in the recuperative power of the animals under consideration. An analogous condition is found in the human subject; given the same solution of continuity, one person recovers much more readily than another. But a comparison between these monkeys and the cases of "Brown-Sequard's paralysis" in man shows a very great difference in the time of the occurrence of restitution. In the latter after many months and even years, no restoration of sensation has been found to occur. In one case (Lancet, 1868, Vol.II Case 3.) twenty one years after

the injury, all forms of sensation were abolished on the side opposite the lesion with the exception of tactile sensibility, which was defective. On the other hand, the return of motor power in man is more active than sensation. In the monkey, sensation was found to return before the motor power.

It therefore appears that, in the monkey at any rate, probably owing to the less highly organised state of its spinal cord, restitution of the sensory functions occurs at a much earlier date after the infliction of an injury than obtains in the highly organised cord of man.

V. The mode in which restoration of function occurs.

I will now very briefly consider how restitution of function takes place. For this purpose it will be necessary to study the return of movement apart from that of sensation, and I have prepared a series of diagrams in order to illustrate the propositions which I have advanced. (plates XV, XVI, & XVII).

A. The restitution of motion.

As has been already stated, the return of movement is in the order from general to special movements, and from those which are more or less bilaterally associated, to those of essentially unilateral motion (Mott). As no tissue regeneration took place at the seat of the lesion, the impressions were probably conveyed to the parts below by the opening up of decussating tracts from the opposite uninjured side. In the first ex-

periment, after nearly complete restitution of the motor functions had taken place, a hemisection of the side of the cord opposite to the original lesion and a few segments higher up produced complete and bilateral paralysis and anaesthesia (plate XVII). Two experiments performed by Rossolymo (1) on guinea pigs are corroborative of this. In one experiment he performed a hemisection of the spinal cord at the tenth dorsal nerve roots, and when the paralysis of the hind limb resulting from this had passed off, he made on the same side another section just behind the decussation of the pyramids. This occasioned paralysis of the fore limb on the same side, while the hind limb escaped. In a second experiment after restoration of the movements resulting from a hemisection in the lower dorsal region, he made a vertical longitudinal incision throughout the lumbar enlargement, with the result that the leg was a second time paralysed.

Dr. Mott's experiments (op.cit.) in stimulating the motor cortex after recovery from the paralysis of a hemisection, confirm this, for he found that excitation of the cortical area of the opposite leg evoked movements in both legs.

The anatomical foundation for this restoration is probably to be obtained in the decussation which is taking place all along the spinal cord by means of the fibres of the anterior

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(1) Rossolymo. Neurol. Centralblatt, 1887, p.292.

commissures, which pass from the direct pyramidal tract of the sound side to the anterior horns of the injured side.

It is not improbable, however, that the so-called "re-crossed fibres" (Sherrington) may be of use in this connection; while a third means may be found in the opening up of hitherto unused, or little used decussating fibres, which pass from the sound to the injured side below the seat of the lesion (plate XV).

That the sound side has taken up the functions of both sides, is I think, evident from the results of the second operation in the first experiment, and from the observations of Rossolymo and Mott.

B. Restoration of sensation.

The experiments have shewn that the forms of sensation which can be determined in animals, viz: tactile and painful sensibility, returned synchronously, with the possible exception of the first experiment. In this it was noted that considerable difficulty was obtained in definitely ascertaining the actual state of the tactile sense. All the experiments showed that painful stimuli, during the first period after restoration, were perceived as sensations of contact. Although the animals localised correctly and their attention was at once arrested by pricking, or the application of the clamp, there was no evidence of any discomfort or annoyance.

There was definite evidence in the fifth operation, and to a slighter extent in the other experiments, of a return of cu-

taneous sensibility in segmental order, i.e. the limbs reacquired sensation proximodistally, being comparable to the restitution of motion from general to special acts.

The bilateral and permanent anaesthesia produced in the first experiment on hemisection of the left side of the cord, after recovery from the previous section of the right side, is indicative of the assumption by the left side of the sensory functions of both. The restitution of the sensory functions then appears to occur by the opening up of straight (nondecussating) paths on the side opposite the hemisection.

Is it possible to place this view on a satisfactory anatomical basis? That commissural fibres are passing between different segments of the spinal cord at all levels on the same side, as well as between the opposite halves of the same segment, no one denies. My contention is that these commissural strands, after hemisection of the spinal cord, take upon themselves the functions of sensory conductors, and convey cutaneous impressions up the same side of the cord as the entering posterior nerve roots. (plates XVI - XVII).

The following is a summary of the general conclusions regarding regeneration, and the return of function after lesions of the spinal cord: -

1. Regeneration of nerve tissue does not occur sequential to lesions of the spinal cord in mammals, and probably not even in the lower vertebrates.

2. There is no return of voluntary motor or sensory functions after complete division of the spinal cord in these animals.

3. Restitution of voluntary motor or sensory functions occurs after hemisection of the spinal cord in monkeys.

4. The return of the motor functions is in the order of general to special movements, and from those which are more bilaterally associated in function, to those which are essentially unilateral.

5. This return of movement probably takes place by means of decussating fibres from the sound towards the wounded side below the lesion.

6. The return of the sensory functions occurs from those parts which are most proximal to those which lie distally.

7. All forms of sensation appear to return first as a sense of contact.

8. The return of sensation probably occurs by the means of straight nondecussating fibres, upon the side opposite to the lesion.

C H A P T E R III.

ON THE ORIGIN OF CERTAIN CRANIAL NERVES.

(Being a clinico-anatomical study of a case of chronic Bulbar Paralysis which has been under the Author's observation).

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Two hypotheses.

The true function of a muscle is not to be ascertained in the dissecting room by observing what its action is when traction is made upon it, or in the living subject when it is made to contract by means of an electric current. Its real function is decided when it is acting in harmony or association with other muscles in the performance of a movement. In a similar way the true nervous supply of this or that muscular structure is not merely to be found in the anatomical distribution of a peripheral nerve, but in the nerve centres which control and regulate certain acts or movements. It is therefore not an uncommon thing to find in the human subject, a peripheral nerve containing fibres, which seem as it were to be included in it by chance, and which have their origin from a nucleus different to that from which the majority of the nerve fibres arise. The consideration of this subject has led one to formulate the following two hypotheses: -

1. That the frontalis and orbicularis palpebrarum muscles although peripherally supplied by the facial nerve, are "eye muscles" and are innervated from the region of the oculo-motor

nucleus.

2. That the lips, soft palate, vocal cords and tongue, although respectively supplied by the facial, vago-accessory, and hypoglossal nerves, form "the organ of articulation" and are innervated from the sphere of the hypoglossal nucleus.

These two hypotheses were formulated after consideration of a case of progressive bulbar paralysis complicated with chronic anterior poliomyelitis, and lateral sclerosis (the so-called amyotrophic lateral sclerosis of Charcot).

The chief clinical features of this case (+) may be briefly abstracted as follows: -

Olfactory nerve - Sense of smell perfectly normal.

Optic nerve - Sight unimpaired; optic discs normal.

Oculo-motor nerves - All ocular movements well carried out. Some coarse nystagmoid jerkings were occasionally observed on extreme lateral deviation - pupils medium and equal, active to light and accommodation - no ptosis.

Trigeminus - (motor branch) ; Paresis almost amounting to paralysis of the masticatory muscles.

(Sensory branch) ; No impairment of sensation - Taste unaffected.

Portio dura - Perfect action of occipito-frontalis and orbicularis palpebrarum: The frontalis is in a state of tonic over-action. The lower facial group of muscles is paralysed: Inability to whistle or to pout the lips.

(+) The Case is fully recorded by Dr. Tooth and myself in "Brain" part 56. p.476.

Portio mollis - Hearing is unimpaired.

Glossopharyngeus - The vomiting reflex is in abeyance.

Vagus and Accessorius vagi - Paralysis of the abductors of the vocal cords ; paralysis of articulation - Paresis of the soft palate.

Hypoglossus - Glossoplegia with wasting.

Spinal accessory - Paresis with wasting of the sterno-mastoid muscles and the upper parts of both trapezii.

The pathological conditions which underly these clinical facts are very definite and suggest the conclusions above mentioned.

1. The oculo-motor nucleus - The ganglion cells of this nucleus, although pigmented to a considerable extent, are not deficient in number and present appearances consistent with health, when compared with the normal nucleus. The issuing fibres of the third nerve are not atrophied (Plate 18 fig 4.)

2. The sections containing the nucleus of the fourth or trochlear nerve were unfortunately lost.

3. The nuclei of the fifth nerve - A portion of this nucleus has been lost with the sections containing the fourth nerve nucleus, but what is seen of it in several sections lower down presents a highly degenerated appearance. The ganglion cells are deficient in quantity and quality. What is seen of th sensory nucleus is of a perfectly normal appearance. (~~Plate fig.~~)

4. The sixth nerve nucleus - The nucleus and intra-medullary fibres of the sixth or abducens nerve are of perfectly normal appearance. (Plate XIX fig.2 .)

5. The seventh nerve nucleus (Portio dura) (Plate 19 fig 3 This nucleus presents very few ganglion cells and those that are present are abnormally rounded, granular and atrophied. The transversely cut compact bundle, which forms the genu facialis in the medulla oblongata, instead of presenting a deep blue appearance from the Weigert - Pal staining, is represented as a sclerosed unstained patch. Under a high power the nerve fibres are found to be completely absent, their place being occupied by a dense neuroglia. The individual fibres of the seventh root are found healthy, although the bundles as a whole are atrophied.

6. The combined glossopharyngeal - vago-accessory nucleu The cells of this nucleus presented a perfectly natural appearance and when compared with those of a normal section presented no diminution in number. The issuing intra-medullary root fibres were of normal size. (Plate XIX fig 1.)

7. The hypoglossal nucleus - (Plate XIX fig 1.) In the mid-segment of this nucleus there is almost complete disappearance of the large characteristic multipolar cells. The normal nucleus contains from thirty to forty such cells in any transverse section ; those from the case under consideration contained four or five ill-shapen cells and sometimes even none at all. The issuing nerve roots of the hypoglossal nerve were

almost entirely atrophied. The ground substance of the normal nucleus, which is formed of a highly characteristic network of medullated fibres, has in this series of sections given place to a dense meshwork of neuroglia, which stained deeply with carmine. The meshwork presented numerous vacuoles, which were probably the spaces out of which the atrophied cells had dropped, when cutting the sections.

I. The nerve fibres which pass by the trunk of the facial nerve to supply the orbicularis palpebrarum and the frontal portion of the occipito-frontalis muscles are probably derived from the oculo-motor nucleus. (+)

One would a priori expect both from its position and function that the orbicularis palpebrarum was closely related to the muscles which move the eye. In the case just narrated a striking contrast existed between the condition of the upper and lower facial groups. In a case, which I have since seen, the contrary was observed; with complete ophthalmoplegia externa there was associated paralysis of the frontalis and orbicularis palpebrarum accompanied with great diminution in their faradic excitability - on the other hand, there was very slight impairment of the movements of the lips and facial muscles.

(+) The corrugator supercilii muscle ought probably to be included in this group. I have no facts bearing directly upon the innervation of the occipital part of the occipito-frontalis other than what is supplied by Text books.

From the pathological description given it appears that the nucleus of the seventh nerve (portio dura) which is almost completely degenerated is probably not the nucleus which presides over the orbicularis palpebrarum and frontalis muscles, which , as we have shown, retained their motor power and were not atrophied. It is suggested that the normal medullated fibres observed in the issuing root of the facial nerve are the nerve fibres for these muscles and that they have come from the oculo-motor nucleus by way of the posterior longitudinal bundles. An experimental research by Mendel of Berlin (+) is to some extent corrobative of this view. He performed experiments after Gudden's method on rabbits and guinea pigs . From six to ten months after he had stitched the eyelids together and detached the muscles from the bone on one side, he killed the animals. Careful examination of the abducens and seventh nerve nuclei failed to show any change in them. The facial trunk on the side of the operation appeared thinner than upon the opposite side. Changes, consisting in great diminution in the number of the ganglion cells and atrophy of their protoplasm, were found in the hinder part of the oculo-motor nucleus - He suggested that the paths of communication between the oculo-motor nuclei and the facial nerve was by the posterior longitudinal bundle.

(+) Mendel.- Neurol. Centralblatt. 1887. No.23.

Since this observation of Mendel's (1887) more attention has been given to the subject of the innervation of the oculo-facial group of muscles apart from the other muscles supplied by the portio dura. I have collected the following recorded facts bearing upon this subject , which lend support to the view already stated.

Birdsall (1) recorded a case of ophthalmoplegia externa, in which there existed diminished electric excitability of the frontalis and orbicularis palpebrarum muscles. I do not lay much weight upon this fact alone, but when it is considered that it may be the first indication of a progressive change in the nerve cells, the fact ought not to be overlooked in this connection.

Boettiger (2) found in a case of nuclear ophthalmoplegia that the dorsal segment of the oculo motor nucleus was perfectly healthy and suggested that this might be a possible source of innervation for the oculo-facial muscular group.

Siemerling (3) from a study of several cases of ophthalmoplegia, suggests, that a small group of cells which lie among the fibres of the posterior longitudinal bundles between the nuclei of the third and fourth nerves, and which he has found to give origin to the fibres which supply the levator palpebrae, may have some relation to the orbicularis palpebrarum

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(1) Birdsall. Journ. of Nerv. and Mental Disease. 1887. p.65
(2) Boettiger. Arch. fur Psychiatrie. Bd. XXI Hft 2.
(3) Siemerling. Arch. fur Pyschiatrie. Bd. XXII Suppl.

Müller (1) described a case of blocking of the upper part of the basilar artery from which there resulted paralysis of the eye muscles and the oculo-facial muscular group.

Spitzkïa (2) from anatomical studies, has come to the conclusion that an aberrant fasciculus from the oculomotor nucleus passes by way of the posterior longitudinal bundles to the genu facialis. While the delimitation by Hitzig of a special centre in the dog's cortex for the eye and eye-face muscles ought not to be overlooked.

It therefore appears from the facts which I have collected and from the original investigations recorded in this chapter, that the oculo-facial muscular group although peripherally supplied through the seventh cranial nerve, is probably innervated not from the seventh nucleus, but from the nucleus or nuclei which innervate the muscles attached to the eye-ball.

II. The muscles which form the organ of articulation viz:- the muscles of the lips, soft palate, vocal cords and tongue, although supplied peripherally through the facial, vago-accessory and hypoglossal nerves receive their central innervation from the nucleus of the hypoglossus.

This has been suggested by the clinical facts of all cases of chronic bulbar paralysis, by the microscopic appearance of the medulla oblongata of the case above recorded, and by certain facts in the comparative and descriptive anatomy of the hypoglossal nucleus.

Chronic bulbar paralysis, the labio-glosso-laryngeal

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(1) Müller. Referred to by Boettiger. op: cit:
(2) Spitzkïa Philadelphia Neurolog: Soc: 1885

palsy of Duchenne, is essentially at any rate at the outset, a disease of the articulatory structures. Its onset is as a rule characterised by a difficulty in forming the lingual consonants, to be soon followed by a defect in the labials and inability to whistle or pout the lips. These symptons are succeeded by a nasal timbre from paralysis of the soft palate.

Later on aphonia and complete paralysis of articulation, reduce the patient to an unhappy condition. On post-mortem examination one finds that the hypoglossal nucleus is the seat of the greatest change, its cells are reduced greatly in number and size, and the fine net-work of medullated fibres which is so characteristic of the healthy nucleus has entirely disappeared.

The combined vago-accessory group of cells presents a normal appearance. (This appears to be the condition in most recorded cases in which the state of the nucleus is noted.)

One has now to enquire how the nerve fibres reach the various muscular structures from their origin in the hypoglossus nucleus..

1. For the orbicularis oris. That the nerve fibres for this muscle course in the facial or seventh nerve throughout its entire length is seen from the facts of anatomical dissection, of Bell's palsy and of disease of the roots within the cranial cavity.

In disease of the facial nucleus alone, the lips escape, as was observed in a case of acute poliencephalitis

of the seventh nucleus recorded by Dr Gowers.(1)

Lockhart Clarke (2) believed that he could trace a portion of the facial nucleus descending as low as the hypoglossus; but this observation has not received confirmation. Whether the fibres for the lips pass to the roots of the facial nerve from the nucleus hypoglossus by the formatio reticularis, or by the posterior longitudinal bundle is not yet known. At all events it seems probable that they do not pass to the nucleus of the seventh nerve itself.

In order to investigate this relation, I have prepared a series of horizontal longitudinal sections of the medulla oblongata and pons Varolii of a monkey.(Macacus)

In a series of sections made at the level of the posterior longitudinal bundles, and passing through the nuclei of the sixth and twelvth cranial nerves, one can discern nerve fibres passing from the region of the hypoglossus nucleus to the genu facialis in the medulla oblongata.

Some of the fibres pass from this nucleus by way of the longitudinal bundles of the same side, while others decussate and pass forwards upon the opposite side. The majority of these fibres forming the posterior longitudinal bundles pass forwards beyond the genu facialis towards the third nerve nucleus, but some apparently pass into the facial nerve in the region of the knee, others take an outward direction and end

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(1) Gowers. Diseases of the Nervous System. 1888 vol 2 p. 222
(2) Lockhart Clarke. Referred to by Gowers (op cit)

in the formatio reticularis grisea. These sections also indicate a probable association through the posterior longitudinal fasciculus between the hypoglossus and abducens nuclei. (Plate XVIII fig 2.)

II. For the muscles of the soft palate and vocal cords.

In a paper which I communicated to the Journal of Anatomy and Phsyiology Vol.XXIII p.523 I showed that anatomical, experimental and clinical evidence were in favour of the vago-accessory nerve being the motor nerve for the muscles of the soft palate and for the following reasons :-

a. That there was not sufficient experimental or clinical proof to support the view that the muscles of the soft palate were supplied by the portio dura.

b. That experimental evidence showed that these muscles were innervated by the internal branch of the spinal accessory nerves, whose fibres are distributed along with certain branches of the vagus.

c. That sufficient clinical evidence existed to prove that paralysis of the soft palate resulted from disease affecting the medullary centre, the roots and the peripheral distribution of the vagus and its accessory nerve.

d. That with the paralysis of the palate there was associated, paralysis of the tongue and of the vocal cords, either unilateral or bilateral according to the situation of the disease.

Dr. John Reid (+) showed that electrical stimulation of the pharyngeal branch of the vagus produced movements of the muscles of the soft palate, while nerve fibres have been traced from the pharyngeal plexus to the palatal muscles (Luschka & Henle). The course of the nerve fibres for the palatal muscles is by the issuing roots of the vago-accessory nerve, which have in all probability been derived from the hypoglossus nucleus, and thence by the trunk of the vagus, its pharyngeal branch and pharyngeal plexus. Stimulation and division of the vago -accessory roots cause movements and paralysis of the vocal cord on the same side. The associated palsy of the palate and vocal cord from peripheral disease has a corresponding association from disease of the medullary centres, as in the condition under discussion.

III. The course of the fibres from the hypoglossus nucleus to the tongue does not require description here.

The relation of the nerves which have just been described to the hypoglossus nucleus now requires consideration.

Lockhart Clarke (1) describes and figures fibres passing from the nucleus of the hypoglossal nerve and apparently from the cells of this nucleus to the issuing fibres of the vago-accessory nerve. He had observed this in the medulla

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(+) John Reid. Physiological, Pathological & Anatomical Researches. Edin. 1849.

(1) Lockhart Clarke - Phil. Trans. 1858.
It is worthy of note that this observation of Clarke's which seems to be of great physiological value has been

oblongata of birds,oxen, sheep and man. It is interesting also to refer here to the origin of the vagus nerve in fishes.
In these animals this nerve has two origins, a lower nongangli onic and an upper ganglionic ; the lower set supply the tongue which is rudimentary and arise in the medulla oblongata. In fishes there is no hypoglossal nerve, but there is a group of cells in the position of the hypoglossus nucleus. The fibres which come from this cell group instead of emerging as a separate nerve pass dorsally and externally to join the issuing roots of the pneumogastric. These fibres are, I believe, analagous to those which pass from the hypoglossus nucleus in man to the vago-accessory nerve to be distributed to the muscles of the soft palate and the vocal cords. (+)

In monkeys (Macacus), a number of whose medulla I have examined to investigate this relation, one observes fibres passing from the fine medullated network of the hypoglossus nucleus outwards towards the issuing roots of the vago-accessory nerve ; while another set pass ventrally to the hypoglos su

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(contd) almost entirely overlooked : I have been unable to discover any reference to it in the usual textbooks, with the single exception of Schwalbe's "Lehrbuch der Neurologie".

(+) Dr. Alex. Bruce has shown me microscopic sections of the medulla of a human foetus, demonstrating a strand of fibres passing from the hypoglossus nucleus to the vago-accessory nerve roots (Private communication.)

nucleus, cross by the raphe and appear to end on the other sid of the medulla either in the hypoglossus nucleus or farther on in the vagus nucleus.

I have endeavoured to represent these relations in Plate I fig. 4, which is a low power view of the connections of the hypoglossus nucleus in Macacus. The dense meshwork of fine medullated fibres, which is highly characteristic of this nucleus both in Man and monkeys is readily seen. Coursing round the ventral aspect of the nucleus one observes a strand of fibres some of which have come from the posterior longitudinal bundle of the same side, while others have come from the longitudinal bundle and the nuclei of the opposite side. This strand of fibres is seen to be joined by medullated fibres coming from the hypoglossus nucleus, which pass to the issuing vago-accessory root fibres without joining the nucleus of that nerve. I believe that the latter set of fibres form an importar part of the vago-accessory nerve, whose existence was originally detected by Lockhart Clarke in birds, oxen, sheep and Man.

I submit in conclusion the following hypothesis:- 1) That the cells of the hypoglossus nucleus are motor and trophic for the muscles of the tongue, the vocal cords, the soft palate and the lips. 2) That these muscles acting in harmony form the organ of articulation. 3) That in chronic bulbar

paralysis in which disease the hypoglossus nucleus is most profoundly affected, there is paralysis of articulation.

4) That the cells which form the nucleus of the vagus and which are left untouched in this disease are "visceral" in function, i.e. they preside over the functions of the heart, the lungs, and the nonstriped muscle of the alimentary canal

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